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# APPARATUS AND METHOD FOR CONTROLLING FLOW OF PROCESS MATERIALS

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Description

# APPARATUS AND METHOD FOR CONTROLLING FLOW OF PROCESS MATERIALS

## Related Applications

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/440,474, filed January 16, 2003, the disclosure of which is incorporated herein by reference in its entirety.

## Technical Field

The present invention relates to material processing equipment. More particularly, the present invention relates to transferring particulate-containing material from a higher pressure environment to a lower pressure environment without significantly damaging the material.

## Background Art

The processing of many food and beverage products requires subjecting the product to high temperatures for a period of time, thereby sterilizing the product. Traditional techniques, such as canning, expose the product to high temperatures for extended periods of time. Canning not only has a high energy cost, but also subjects the product to thermal stress, which frequently has a negative impact on the flavor and texture of the product.

More recent techniques involve aseptic processing, in which liquid foods and beverages are sterilized outside the package using an ultra-high temperature process that rapidly heats, and then cools, the product before packaging. The processing equipment allows the time (generally 3 to 30 seconds) and temperature (195° to 300° F) to be tailored to place the least amount of thermal stress on the product, while ensuring safety. The rapid heating and cooling aspects of the aseptic process substantially reduce the energy use and nutrient loss associated with conventional techniques. As a result, aseptically packaged products retain more nutritional value and exhibit more natural texture, color, and taste.

The rapid heating and cooling steps of the aseptic process typically take place while the product is being piped from one vessel to another. A portion of the pipe is heated and, as the product passes through the heated portion of the pipe, heat is transferred to the product. The product within the pipe is under pressure, typically 50 to 100 psi, which serves to move the product through the pipe and also prevent vaporization of the water component of the product within superheated sections. Subsequent operations, such as packaging, normally require lower pressures, typically up to 15 psi. Thus, the product must go though a pressure reduction step before packaging.

Many designs of back-pressure or pressure reduction valves exist for single-phase fluids. However, these valves cause significant shear damage to sensitive fluids and particulate-containing liquids. Moreover, the valves can become clogged with particulates, which can damage the valve and potentially cause a rupture.

Accordingly, there is a need to provide a pressure reduction valve that can be used to transfer a continuous flow of particulate-containing material from a higher pressure environment to a lower pressure condition without significant damage to the particulates contained in the material.

## Disclosure of the Invention

In accordance with the invention, an apparatus for controlling the flow of a process material is provided. The apparatus includes a first chamber and a second chamber. Each chamber has a rigid outer shell and is divided into a first and a second region by a flexible boundary. The second region of each chamber is filled with a non-compressible fluid. An inlet flow control device is arranged to provide fluid communication between a material input line and alternately the first region of the first chamber and the first region of the second chamber. An outlet flow control device is arranged to provide fluid communication between a material output line and alternately the first region of the second chamber and the first region of the first chamber. A chamber control device is arranged to provide fluid communication between the second region of the first chamber and the second region of the second chamber.

In accordance with another aspect of the present invention, a method for transferring a material from a high pressure environment to a low pressure environment is provided. The method includes arranging an input flow control device to provide a flow of material from a high pressure conduit into a first region of a first chamber and arranging an output flow control device to provide a flow of material from a first region of a second chamber into a low pressure

conduit. The method also includes arranging a chamber control device between a second region of the first chamber and a second region of the second chamber, thereby providing fluid communication between the respective second regions of the first and second chambers. The first and second region of each chamber is separated by a flexible boundary. The method also includes controlling a flow of non-compressible fluid from the second region of the first chamber to the second region of the second chamber.

In accordance with another aspect of the invention, the method for transferring a material from a high pressure environment to a low pressure environment includes arranging, after a time, the input flow control device to provide a flow of material from the high pressure conduit into the first region of the second chamber, arranging the output flow control device to provide a flow of material from the first region of the first chamber into the low pressure conduit, and controlling the flow of non-compressible fluid from the second region of the second chamber to the second region of the first chamber.

In accordance with yet another aspect of the invention, a method for transferring a process material from a high pressure environment to a lower pressure environment is provided. The method includes opening an input flow control device arranged to provide a flow of material from a high pressure conduit into a first region of a chamber intended to be filled with process material and opening an output flow control device arranged to provide a flow of material from a first region of a chamber intended to be emptied of process material into a low pressure conduit. A chamber control device arranged to

control the flow of non-compressible fluid between a second region of the chamber being filled with process material and a second region of the chamber being emptied of process material may be adjusted to regulate the rate at which process material flows into and out of the respective chambers. The first and second region of each chamber is separated by a flexible boundary. Based on predetermined conditions, the chamber to be emptied of process material may be switched with the chamber to be filled with process material by opening and closing the appropriate input and output flow control devices.

Accordingly, the present invention provides a method and apparatus for transferring a continuous flow of particulate-containing material from a higher pressure environment to a lower pressure condition without significant damage to the particulate contained in the material.

Some of the objects of the invention having been stated hereinabove, and which are addressed in whole or in part by the present invention. Other objects will become evident as the description proceeds when taken in connection with the accompanying drawings as best described hereinbelow.

## Brief Description of the Drawings

Figure 1 is a schematic diagram of an embodiment of a device for transferring a continuous flow of particulate-containing material from a higher pressure environment to a lower pressure environment in accordance with the invention;

Figure 2 is a vertical cross-sectional view of chamber **106A** viewed along line 2—2 in Figure 1;

Figures 3A and 3B illustrate alternate steps in the operation of the device in accordance with the invention;

Figure 4 is a schematic diagram of another embodiment of the device in accordance with the invention;

Figure 5 is a vertical sectioned view of an exemplary embodiment of chamber **412** in accordance with one aspect of the invention; and

Figure 6 is a flow diagram of a method for transferring a continuous flow of particulate-containing material from a higher pressure environment to a lower pressure environment in accordance with an aspect of the invention.

## Detailed Description of the Invention

For convenience, certain terms employed in the specification, examples, and appended claims are collected here. While the following terms are believed to be well understood by one of ordinary skill in the art, the following definitions are set forth to facilitate explanation of the presently disclosed subject matter.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which the presently disclosed subject matter belongs. Although any methods, devices, and materials similar or equivalent to those described herein can be used in the practice or testing of the presently disclosed subject matter, representative methods, devices, and materials are now described.

As used herein, an "inlet flow control device" and an "outlet flow control device" include a valve or other suitable mechanism that may be used to

control the flow of a material from one region to another. The flow control devices may include a backflow prevention mechanism.

As used herein, a "chamber control device" includes a flow control valve that may be adjusted to control the rate of flow of a fluid from one chamber to another. The chamber control device may provide finite levels of flow control between a minimum and a maximum flow or it may be infinitely adjustable between the minimum and maximum flow.

As used herein, "communication" or "fluid communication" means arranging two or more conduits, chambers, vessels, or the like to allow material within one conduit, chamber, or vessel to be in contact with material within another conduit, chamber, or vessel such that the material may flow from one conduit, chamber, or vessel to another with the application of a differential pressure.

Figure 1 is a schematic diagram of an embodiment of a device for transferring a continuous flow of particulate-containing material from a higher pressure environment to a lower pressure environment in accordance with the invention. Device **100** includes a high pressure conduit **102** having a proximal or first end and a distal or second end. The first end of the high pressure conduit **102** may be connected to a reservoir or other source of particulate-containing material (not shown). The second end of the high pressure conduit **102** may be connected to the first end of two or more inlet valves **104A, 104B**. The inlet valves **104A**, **104B** may be opened to permit the flow of material through the valve or closed to prevent the flow of material. In Figure 1, inlet valve **104A** is shown in the closed position and inlet valve **104B** is shown in the

open position. The second or distal end of each inlet valve **104A**, **104B** is connected to a first end of a respective chamber **106A**, **106B**.

The second end of each of chambers **106A**, **106B** is connected to the first end of a respective one of outlet valves **108A**, **108B**. The outlet valves **108A**, **108B** may be opened to permit the flow of material through the valve or closed to prevent the flow of material. In Figure 1, outlet valve **108A** is shown in the open position and outlet valve **108B** is shown in the closed position. The second end of each of outlet valves **108A**, **108B** is connected to the first end of a low pressure conduit **110**. The second end of the low pressure conduit **110** may, in turn, be connected to low pressure equipment, such as a dispensing apparatus (not shown).

The chambers **106A**, **106B** each have a rigid outer wall **112A**, **112B**, respectively. A flexible conduit **114A**, **114B** extends from the first end of a respective chamber **106A**, **106B** to the second end of the chamber. The flexible conduits **114A**, **114B** divide the chambers **106A**, **106B** into inner lumens **116A**, **116B** and outer lumens **118A**, **118B**. As shown in Figure 2, which is a cross-sectional view of chamber **106A** viewed along line 2—2, the outer lumens **118A**, **118B** coaxially surround the inner lumens **116A**, **116B** of chamber **106A**, **106B**.

In accordance with one aspect of the invention, the outer lumens **118A**, **118B** of chambers **106A**, **106B** are filled with a non-compressible fluid **120**. The outer lumen **118A** of chamber **106A** is connected to the outer lumen **118B** of chamber **106B** by a tube **122**. The tube **122** has a controllable flow valve

**124** that controls the flow rate of the non-compressible fluid **120** between the outer lumens **118A, 118B** of each of chambers **106A, 106B**.

Figures 3A and 3B illustrate alternate steps in the operation of the device **100** in accordance with the invention. In Figure 3A, inlet valve **104A** is closed and inlet valve **104B** is open, which permits the particulate-containing material **M** to flow into the inner lumen **116B** of chamber **106B**. Since outlet valve **108B** is closed, the material **M** collects in the inner lumen **116B** and causes the walls of flexible conduit **114B** to expand toward the outer wall **112B** of chamber **106B**. The expansion of the flexible conduit **114B** displaces non-compressible fluid **120** in the outer lumen **118B**. The displaced fluid **120** flows through tube **122** and into outer lumen **118A** of chamber **106A**.

As the volume of non-compressible fluid **120** in outer lumen **118A** increases, the walls of flexible conduit **114A** are forced inward, reducing the volume of inner lumen **116A**. Since outlet valve **108A** is open, the contracting walls of expandable conduit **114A** push material **M** out of the inner lumen **116A**, through outlet valve **108A**, and into low pressure conduit **110**.

It should be appreciated that the volume of material **M** that flows into the inner lumen **116B** displaces an equal volume of non-compressible fluid **120** out of outer lumen **118B**. Similarly, the volume of non-compressible fluid **120** that flows into outer lumen **118A** displaces an equal volume of material **M** from inner lumen **116A**. As noted above, the fluid **120** that is displaced from the outer lumen **118B** of chamber **106B** flows through the tube **122** and into the outer lumen **118A** of chamber **106A**. The rate at which fluid **120** flows from

outer lumen **118B** to outer lumen **118A** determines how quickly material **M** can flow into the inner lumen **116B** and out of inner lumen **116A**, respectively. The control flow valve **124** regulates the flow of the non-compressible fluid **120** through the tube **122** and, as a result, the rate at which material **M** flows into and out of the respective chambers.

In Figure 3B, inlet valve **104B** is closed and inlet valve **104A** is open, which permits particulate-containing material **M** to flow into the inner lumen **116A** of chamber **106A**. Since outlet valve **108A** is closed, the material **M** collects in inner lumen **116A** and causes the walls of the flexible conduit **114A** to expand toward the outer wall **112A** of chamber **106A**. The expansion of the flexible conduit **114A** displaces non-compressible fluid **120** in the outer lumen **118A**. The displaced fluid **120** flows through tube **122** and into outer lumen **118B** of chamber **106B**.

As the volume of non-compressible fluid **120** in outer lumen **118B** increases, the walls of flexible conduit **114B** are forced inward, reducing the volume of inner lumen **116B**. Since outlet valve **108B** is open, the contracting walls of flexible conduit **114B** push material **M** out of the inner lumen **116B**, through outlet valve **108B**, and into the low pressure conduit **110**.

By alternately opening and closing the inlet and outlet valves as shown in Figures 3A and 3B, device **100** transfers material **M** from a high pressure environment to a lower pressure environment. The inner lumen of each chamber is alternately filled with then emptied of the particulate-containing material. As the lumen of one flexible conduit fills, the surrounding non-compressible fluid flows through the connecting tube and flow control valve into

the outer lumen of the other chamber, forcing material out of the inner lumen at a flow rate determined by the flow-control valve. This system allows for the transfer of particulate containing material from a high-pressure environment to a lower pressure environment without significant mechanical damage to the particles. Moreover, the flow rate of the material is adjustable by controlling the rate at which the non-compressible fluid flows from one chamber to the other.

Figure 4 is a schematic diagram of another embodiment of the device in accordance with the invention. Device **400** includes a high pressure conduit **402** having a proximal or first end and a distal or second end. The first end of the high pressure conduit **402** may be attached to a reservoir or other source of particulate-containing material (not shown). The second end of the high pressure conduit **402** may be connect to the first end of two or more inlet valves **404A, 404B**. Inlet valves **404A, 404B** may be opened to permit the flow of material through the valve or closed to prevent the flow of material. In Figure 4, inlet valve **404B** is shown in the closed position and inlet valve **404A** is shown in the open position. The second or distal end of each inlet valve **404A, 404B** is connected to a first end of a respective one of transition conduits **406A, 406B**. Transition conduits **406A, 406B** each divide into two branches. One branch of each of the transition conduits **406A, 406B** connects to the first end of a respective outlet valve **408A, 408B**. Outlet valves **408A, 408B** may be opened to permit the flow of material through the valve or closed to prevent the flow of material. In Figure 4, outlet valve **408A** is shown in the closed position and outlet valve **408B** is shown in the open position. The second end of each of outlet valves **408A, 408B** is connected to a respective one of the first ends

**410A**, **410B** of a low pressure conduit **410**. The second end of the low pressure conduit **410** may, in turn, be connected to low pressure equipment, such as a dispensing apparatus (not shown).

The other branch of each of the transition conduits **406A, 406B** connects to a respective chamber **412A, 412B**. Chambers **412A, 412B** have a rigid outer wall **414A, 414B**, respectively. Flexible diaphragms **416A, 416B** divide each chamber **412A, 412B**, respectively, into a first region **418A, 418B**, respectively, and a second region **420A, 420B**, respectively. The first regions **418A, 418B** are in fluid communication with the lumens of the transition conduits **406A, 406B**. The second regions **420A, 420B** of chambers **412A, 412B** are filled with a non-compressible fluid **422**. A tube **424** connects the second region **420A** of chamber **412A** to the second region **420B** of chamber **412B**. The tube **424** has a control flow valve **426** that controls the flow rate of the non-compressible fluid **422** between the second regions **420A, 420B** of the chambers **412A, 412B**. If desired, the rate of flow of the non-compressible fluid **422** may be measured using a flow meter **428** or similar device.

The principle of operation of the device depicted in Figure 4 is the same as that of the device depicted in Figures 1-3. Particulate-containing material **M** flows through the open inlet valve **404A** and into the transition conduit **406A**. Since the outlet port **408A** is closed, the material **M** flows into the first region **418A** of the chamber **412A**. As the first region **418A** of the chamber **412A** fills with material **M**, the material **M** pushes against the flexible diaphragm **416A** causing the first region **418A** to expand and the second region **420A** to

contract. Non-compressible fluid **422** is displaced from the second region **420A** of the chamber **412A** into the tube **424**. The fluid flows through the tube and into the second region **420B** of chamber **412B**. As the volume of fluid in the second chamber increases, the fluid pushes against the flexible diaphragm **416B**, displacing material **M** from the first region **418B** of the chamber **412B**. The displaced material **M** flows into the transition conduit **406B**. Since inlet valve **404B** is closed and outlet valve **408B** is open, the material **M** flows through the outlet valve **408B** and into the low pressure conduit **410**. Closing inlet valve **404A** and outlet valve **408B**, and opening inlet valve **404B** and outlet valve **408A** causes chamber **412B** to fill with material **M** and chamber **412A** to empty. As in the previous embodiment, the rate at which the chambers fill and empty can be controlled by adjusting the flow rate of the non-compressible fluid using the control flow valve **426**.

The devices **100**, **400** may be constructed using commercially available materials and conventional techniques. For example, conduits **102**, **110**, **402**, **406**, and **410** may be formed from a material capable of withstanding high temperatures and pressures, such as stainless steel. One skilled in the art would recognize that materials such as stainless steel are available in a variety of grades depending on the intended application. Accordingly, the specific grade of material should be matched to the intended application. For example, for food applications, a food-grade stainless steel may be selected.

Flexible conduits **114** and flexible diaphragms **416** may be formed from a flexible material that is suited to high temperatures and pressures, as well as compatible with the material being processed. Suitable materials may include

rubber and fluoroelastomers, such as VITON® from DuPont Dow Elastomers, LLC.

Valves **104**, **108**, **404**, and **408** may be an on/off pneumatic actuator diaphragm valve system, such as one of the ADVANTAGE® series of Pure-Flo® valves from ITT Industries. As noted above, valves **104**, **108**, **404**, and **408** are either in the open or closed position. Fine adjustment of the aperture size of the valves is not presently needed during the normal operation of the device. Thus, a simple on/off actuator is adequate. Diaphragm-style valves are widely employed in food and pharmaceutical processing applications.

Flow control valves **124** and **426** may require finer adjustment of aperture size to reach the desired flow rate. As such, a conventional flow regulating valve may be used.

Figure 5 is a sectioned view of an exemplary embodiment of chamber **412** in accordance with one aspect of the invention. The chamber **412** is formed from a concave base **502** and a concave lid **504**. As shown in Figure 5, the base has a substantially closed, flat bottom **506**, angled sidewalls **508**, and an open top **510**. An aperture **512** extends through a portion of the bottom **506** of the base **502** and may attach to the transition conduit **406** such that the interior **513** of the base **502** is in fluid communication with the lumen of the transition conduit **406**. A rim **514** is formed around the perimeter of the open top **510** of the base **502**.

The lid **504** is of the same general size and shape as the base **502**, but is oriented in the opposite direction. Thus, the lid has a substantially closed, flat top **516**, angled sidewalls **518**, and an open bottom **520**. One or more

apertures **522**, **524** may extend through the top. One aperture **522** may provide fluid communication between the tube **424** and the interior **526** of the lid **504**. A second aperture **524** may provide access to a guide shaft **528**, the lumen of which is in fluid communication with the interior **526** of the lid **504**. A rim **530** is formed around the perimeter of the open bottom **520** of the lid **504**.

The chamber includes a flexible diaphragm **532**, which is sandwiched between the respective rims **510**, **530** of the base **504** and lid **502**, and mechanically sealed, for example, using a clamp **546**, to form two watertight vessels capable of being pressurized. Plates **534**, **536** are positioned on each side of the diaphragm to provide support for a piston **538**. The plates **534**, **536** are substantially smaller in diameter than the diaphragm **532** and do not significantly interfere with the flexibility of the diaphragm **532**. The piston **538** extends through the upper vessel **540** from the diaphragm **532** into the guide shaft **528**. The upper vessel **540** is filled with a non-compressible fluid **422**, such as water.

During the operation of the device **400**, the diaphragm **532** moves between the upper **540** and lower **544** vessels as the respective vessels fill and empty. The movement of the diaphragm **532** results in a corresponding movement of the piston **538** in the guide shaft **528**. As discussed below, it may be desirable to place sensors in or around the guide shaft to determine the position of the piston within the guide shaft. The guide shaft may also be fitted with a pressure gauge to monitor the interior pressure of the vessel.

As noted above, devices **100**, **400** transfer material **M** from a high pressure environment to a low pressure environment by opening and closing the inlet and outlet valves as shown, for example, in Figures 3A and 3B. Figure 6 is a flow diagram of the steps that may be followed to operate devices **100**, **400**. In step **ST1**, all of the input and output valves may be closed. Although this step is optional, momentarily closing all of the input and output valves ensures that the input and output valves associated with the same chamber are not open at the same time. As noted above, opening the input and output valves associated with the same chamber would permit process material to flow unchecked from the high pressure conduit to the low pressure conduit, which is not desirable.

In steps **ST2** and **ST3**, the input valve for the chamber to be filled with process material is opened and the output valve for the chamber to be emptied of process material is opened. The order of these steps is arbitrary, since the flow of process material will not occur until both an input valve and an output valve are opened. Thus, step **ST3** may be performed prior to, simultaneously with, or after step **ST2**.

In step **ST4**, the output flow rate of the process material is checked. If the rate is too high or too low, the flow rate of the non-compressible fluid is adjusted using the flow control valve (step **ST5**). As noted above, the flow rate of the non-compressible fluid between the chambers controls how quickly one chamber fills and the other chamber empties.

In step **ST6**, a decision is made whether to switch chambers. If the decision is made to switch chambers, processing continues with step **ST1**. It

should be appreciated that in each pass through the process loop shown in Figure 6, the roles of the chambers is reversed. Thus, the chamber that was filled during one pass is emptied during the next and the chamber that was emptied during one pass is filled during the next. The decision to switch chambers may be done at a fixed interval of time or as the result of some other signal.

While the chambers may be switched at fixed intervals, this may result in sub-optimum performance of the device. For example, if the valves are closed before the chamber is completely filled or emptied of material then the device is not transferring as much material as possible with each cycle. Likewise, if there is a delay between the point when the chamber is completely full or completely empty and the valves are closed, the device is transferring the maximum amount of material in each cycle, but the cycle lasts longer than necessary. As noted above, the rate at which the material flows into and out of the chambers depends on the rate of flow of the non-compressible fluid between the chambers. However, the flow rate of the material also depends on other factors, such as the amount of pressure applied to the material in the high pressure conduit, the length and inner diameter of the high pressure conduit, and the viscosity of the material. Thus, changes in any of these factors may cause the device to perform at a sub-optimum level. By using one or more sensors in or around the chambers, the capacity of the chambers may be monitored and the timing of each cycle may be adjusted to achieve optimum performance of the device.

It will be understood that various details of the invention may be changed without departing from the scope of the invention. For example, other sensitive or viscous materials may be used in place of the particulate-containing material in the operation of the apparatus described herein. Such materials include sheer sensitive materials, including biological components, and materials having suspended slurry or crystalline components. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation, as the invention is defined by the claims as set forth hereinafter.